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Enumeration of *Campylobacter* spp. in Broiler Feces and in Corresponding Processed Carcasses

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ABSTRACT

Twenty north Georgia commercial flocks of broiler chickens sampled in 1995 and 11 flocks sampled in 2001 were tested for *Campylobacter* spp. Direct plating on Campy-Cefex agar was carried out to determine levels of *Campylobacter* colonization within each flock through the enumeration of the organism in 50 fresh fecal samples 1 day prior to slaughter. The next morning, these flocks were the first to be processed, and levels of the organism per carcass before the chilling operation (50 carcasses per flock) in 2001 and after the chilling operation (50 carcasses per flock) in both 1995 and 2001 were estimated. Levels of the organism on freshly processed broiler carcasses were estimated by the same methods in 1995 and 2001, and a significant reduction from an average of $10^{4.11}$ CFU per carcass in 1995 to an average of $10^{3.05}$ CFU per carcass in 2001 was observed. Levels of *Campylobacter* spp. found in production and in processing were not strongly correlative, indicating the existence of complex parameters involving production factors and variables associated with flock transport and the processing of the broilers. The reduction in *Campylobacter* levels on processed carcasses may have contributed to the reduction in the frequency of human disease observed by the Centers for Disease Control during the same period. These data characterize the distribution of *Campylobacter* in north Georgia poultry operations and should assist in the development of risk assessment models for *Campylobacter* spp. The results obtained in this study suggest that the implementation of antimicrobial interventions by the poultry industry has already reduced consumer exposure to the organism.

Campylobacter spp. are the most frequently reported human bacterial enteropathogens in developed countries *(4)* and worldwide *(3, 5).* Case-control epidemiological studies have indicated that mishandled or improperly prepared chicken products are associated with the transmission of *Campylobacter* spp. to humans *(1, 7, 14). Campylobacter* spp. are readily isolated from chicken broiler farms and from carcasses in poultry processing plants *(2, 17, 19).* Poultry has frequently been implicated as a vehicle for sporadic foodborne campylobacteriosis *(6).* Harris et al. *(9)* estimated that 48% of *Campylobacter* cases could be traced back to the mishandling or consumption of contaminated poultry products. Over the past decades, poultry consumption has increased in the United States and throughout the world, and the potential for exposure to and transmission of *Campylobacter* spp. has increased with it *(2).* The poultry industry has long sought measures to reduce the exposure of consumers to *Campylobacter* spp.

In the United States, a reduction in the frequency of campylobacteriosis has been observed. The Centers for Disease Control and Prevention (CDC), through their active FoodNet surveillance system in the United States, have found that in 1996 the annual incidence of campylobacteriosis was 23.5 human cases per 100,000 individuals and that in 1999 the frequency dropped to 17.5 per 100,000 individuals. Dr. Robert Tauxe of the CDC states, ''These are sustained and important declines . . . we are headed in the right direction'' *(11).* This substantial reduction in the campylobacteriosis rate suggests that the exposure of the human population to *Campylobacter* spp. has been reduced. If poultry is considered the major source of human campylobacteriosis, there may have been a concomitant reduction in exposure to *Campylobacter* spp. through poultry products. In the present study, initiated in 1995, 20 independent broiler flocks sampled at the completion of broiler production at a broiler processing facility in northern Georgia were tested for *Campylobacter* spp. Eleven additional flocks sampled at broiler production facilities in the same geographical area were analyzed in 2001. To minimize the likelihood that previous flocks could serve as confounding sources of contamination, carcasses from the first flocks processed during the day were sampled. The objective of this work was to determine whether levels on the farm were related to levels after poultry processing and whether levels of consumer exposure had diminished from 1995 to 2001.

MATERIALS AND METHODS

Over a 10-month period in 1995, 20 commercial broiler chicken flocks (ca. 20,000 birds each) were monitored at the completion of the broiler production cycle (these birds were ca. 56 days old). Fifty fresh fecal specimens were collected the day before the sampled flocks were scheduled to be processed. Random fecal droppings deposited throughout the production facility were aseptically collected, with clean disposable gloves being used for each sample. Each individual specimen was placed into a sterile disposable 50-ml centrifuge tube and transported within 1 h to the

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laboratory in an insulated container half filled with chipped ice. At the laboratory, sample weights were taken and decimally diluted, and 0.1 ml of each dilution was surface spread plated onto duplicate Campy-Cefex plates *(25)* that had been dried at room temperature overnight to enhance the production of isolated colonies. The inoculated plates were incubated for 48 h in a microaerobic atmosphere (5% O_2, 10% CO_2, and 85% N_2) at 42°C. Characteristic colonies were presumptively identified through the observation of typical morphological characteristics and motility with the use of phase-contrast microscopy, and levels of *Campylobacter* spp. were determined *(23)*. One or two presumptive colonies randomly selected from each plate were confirmed by a commercial latex agglutination test (Integrated Diagnostics, Inc., Baltimore, Md.). Arithmetic counts of CFU per gram of feces or per carcass were converted into $\log_{10}$ values.

Individual flocks were transported to the processing plant in commercial trucks, and each flock assayed was the first group of birds processed on the morning after fecal samples were collected. The flocks were routinely processed, and 50 random carcasses were aseptically placed in clean plastic bags as they exited the final immersion chiller. During the 1995 sampling period, no chlorine had been added to the chill tank makeup waters. Each carcass sample was rinsed in 100 ml of sterile tap water for 1 min *(22)*. Rinse samples were held on ice for ca. 1 h during transport to the laboratory. Analysis to determine *Campylobacter* counts for carcasses was carried out as described above. Since 0.1 ml of rinse suspension from the total rinse volume of 100 ml was plated, a failure to detect the organism represented an estimated <1,000 CFU per carcass.

We similarly sampled 11 flocks in 2001. An additional 50 carcasses per flock were sampled before they entered the chill tank, and 50 carcasses were sampled after they had been fully processed. Levels of *Campylobacter* spp. in these carcasses were estimated. After rinse sampling, the carcasses were put back onto the processing lines. The prechill carcasses were not labeled and were unlikely to be the same carcasses sampled after immersion in the chill tank. By 2001, significant commercial modifications in processing procedures had been instituted in this processing plant and throughout the industry. During 2001, the use of counterflow immersion chilling involving the use of 40- to 50-ppm-chlorine makeup waters had become industry practice. Levels of chlorine in the overflow waters were ca. 1 to 2 ppm. Additionally, the amount of water used had been increased from an average of 4 to 5 gal (16.9–21.1 liters) per carcass to >8 gal (33.8 liters) per carcass. Both of these industrywide changes were consistent with the implementation of hazard analysis critical control point (HACCP) plans. Additionally, flock sizes had increased relative to 1995 (to an average of >25,000 birds per flock).

Student's *t* test results, critical values for correlation coefficients, mean and median values, and Pearson correlations were calculated with the use of Excel software.

RESULTS

Campylobacter counts were determined for ca. 3,250 fecal and carcass samples. Table 1 contains the means of $\log_{10}$ values for levels of *Campylobacter* spp. for fecal specimens sampled from 1995 flocks. The data for flock 2 were excluded because of a laboratory accident. Of the 948 fecal samples collected, 914 (96.4%) tested positive for *Campylobacter* spp. *Campylobacter* concentrations were undetectable for 34 individual droppings, and the highest level of colonization was $10^{7.87}$ CFU/g (for individual 23 in flock 17). The prevalence of *Campylobacter* spp. in fecal samples collected from the 19 flocks monitored ranged from 86 to 100% per flock. The mean level of *Campylobacter* spp. was $10^{4.93}$ CFU/g of feces collected from the 19 flocks in 1995.

TABLE 1. Campylobacter *counts for mature broiler chickens sampled in 1995*

Flock no.	*Campylobacter* count ($\log_{10}$ CFU/g) for feces samples[a]	*Campylobacter* count ($\log_{10}$ CFU/g) for carcass rinses[b]
1	5.31 (1.09)	4.14 (0.41)
2	—[c]	—[c]
3	5.01 (0.92)	3.83 (1.38)
4	4.31 (1.10)	2.99 (1.91)
5	4.59 (0.85)	3.87 (1.35)
6	4.90 (2.12)	4.11 (0.93)
7	6.04 (0.74)	3.56 (1.42)
8	4.43 (1.52)	3.40 (1.37)
9	4.83 (1.91)	3.62 (1.28)
10	4.89 (0.85)	4.72 (0.79)
11	3.72 (1.59)	4.00 (1.13)
12	5.21 (1.04)	3.82 (0.70)
13	4.66 (1.59)	4.78 (0.49)
14	3.73 (1.29)	4.58 (1.02)
15	5.53 (1.05)	4.53 (0.47)
16	5.29 (0.74)	4.53 (0.42)
17	6.01 (1.09)	5.73 (0.25)
18	5.07 (0.87)	4.08 (0.43)
19	5.71 (0.73)	4.55 (0.52)
20	4.51 (2.03)	3.27 (1.29)
Average	4.93 (1.22)	4.11 (0.92)

[a] Mean (standard deviation). Fifty random droppings were collected 1 day prior to the slaughter of the flock. A value of 0.01 $\log_{10}$ CFU/g was assigned to samples with undetectable levels of *Campylobacter* spp.

[b] Mean (standard deviation). Rinses were obtained for 50 postchill carcasses. A value of 0.01 $\log_{10}$ CFU per carcass was assigned to samples with undetectable levels of *Campylobacter* spp.

[c] The data for flock 2 were excluded because of a laboratory accident.

Table 1 also contains data for fully processed carcasses from the flocks assayed in 1995. Of the 943 carcass rinses collected, 887 (94.1%) tested positive for *Campylobacter* spp. The highest concentration of *Campylobacter* spp. was $10^{6.32}$ CFU per carcass rinse (for individual 33 in flock 17). Concentrations for all tested carcasses from flock 17 were found to be $>10^{5.16}$ CFU per carcass rinse, with concentrations for seven individual processed carcasses exceeding $10^{6.0}$ CFU per carcass rinse. The prevalence levels of *Campylobacter* spp. in flock carcasses ranged from 72 to 100% for samples tested in 1995. Generally, when a reduced frequency of positive carcasses in a flock was recorded, a reduced concentration of *Campylobacter* spp. was also observed.

Table 2 contains data for the fecal specimens collected from nine flocks in 2001. Results for two additional flocks that had been sampled are excluded from the reported data because of a laboratory accident involving the first flock and because the second flock was not colonized and did

TABLE 2. Campylobacter *counts for mature broiler chickens sampled in 2001*[a]

Flock no.	Mean *Campylobacter* count (SD)[b]	Mean *Campylobacter* count (95% CI)[c]	Median *Campylobacter* count (95% CI)
No. fecal samples			
1	5.29 (1.97)	5.43 (5.02–5.89)	5.98 (5.33–6.17)
2	4.96 (1.62)	5.05 (4.67–5.43)	5.25 (4.88–5.67)
3	6.16 (0.93)	6.16 (5.90–6.43)	6.17 (6.03–6.39)
4	4.68 (2.14)	4.84 (4.33–5.36)	5.14 (4.33–5.67)
5	4.89 (1.56)	4.95 (4.56–5.34)	5.30 (4.67–5.60)
6	5.42 (1.63)	5.49 (5.08–5.89)	5.69 (5.18–6.21)
7	4.31 (2.28)	4.63 (4.15–5.10)	5.12 (4.75–5.49)
8	5.23 (0.83)	5.23 (5.00–5.47)	5.22 (5.09–5.49)
9	5.50 (1.22)	5.50 (5.15–5.84)	5.61 (5.02–6.16)
Average	5.16	5.25	5.50
Prechill carcasses			
1	4.67 (0.40)	4.67 (4.56–4.78)	4.67 (4.57–4.76)
2	4.75 (0.40)	4.75 (4.64–4.87)	4.80 (4.60–4.92)
3	4.98 (1.09)	5.09 (4.91–5.26)	5.15 (4.98–5.33)
4	4.55 (1.04)	4.66 (4.49–4.83)	4.74 (4.59–4.83)
5	4.33 (0.57)	4.33 (4.17–4.49)	4.27 (4.11–4.46)
6	4.65 (1.43)	4.87 (4.66–5.08)	4.99 (4.89–5.11)
7	4.76 (0.80)	4.81 (4.67–4.96)	4.79 (4.64–4.95)
8	4.65 (0.25)	4.65 (4.58–4.72)	4.65 (4.53–4.75)
9	5.41 (0.33)	5.41 (5.31–5.50)	5.35 (5.32–5.49)
Average	4.75	4.80	4.82
Postchill carcasses			
1	2.27 (1.48)	3.02 (2.89–3.15)	2.70 (2.70–3.18)
2	2.10 (1.57)	3.01 (2.88–3.14)	2.70 (2.70–3.00)
3	3.45 (0.68)	3.51 (3.37–3.64)	3.54 (3.40–3.74)
4	2.69 (1.41)	3.23 (3.09–3.37)	3.18 (3.00–3.40)
5	2.16 (1.55)	3.02 (2.89–3.15)	2.70 (2.70–3.00)
6	3.33 (1.06)	3.49 (3.30–3.70)	3.44 (3.18–3.70)
7	3.84 (0.40)	3.84 (3.73–3.96)	3.78 (3.65–3.93)
8	2.87 (1.33)	3.30 (3.16–3.44)	3.24 (3.18–3.48)
9	4.59 (0.48)	4.59 (4.45–4.73)	4.52 (4.39–4.75)
Average	3.03	3.45	3.31

[a] Fifty random droppings were taken 1 day prior to the slaughter of a flock, and rinses were obtained for 50 randomly selected prechill and 50 randomly selected postchill carcasses from each flock on the processing line. CI, confidence interval. Counts are expressed as $\log_{10}$ CFU/g for feces samples and as $\log_{10}$ CFU per carcass for prechill and postchill carcasses.

[b] A value of 0.01 $\log_{10}$ CFU/g (for feces samples) or 0.01 $\log_{10}$ CFU per carcass (for prechill and postchill carcasses) was assigned to samples with undetectable levels of *Campylobacter* spp.

[c] A value of 1.60 $\log_{10}$ CFU/g was assigned to feces samples with undetectable levels of *Campylobacter* spp., and a value of 2.69 $\log_{10}$ CFU per carcass was assigned to prechill and postchill carcass rinses with undetectable levels of *Campylobacter* spp.

not yield carcasses contaminated with *Campylobacter* spp. Of the 450 fecal droppings sampled from the nine flocks, 423 (94%) were colonized. *Campylobacter* concentrations were undetectable in 27 samples, and the highest level of colonization was $10^{8.06}$ CFU/g of feces (for individual 22 in flock 9). The average level of *Campylobacter* spp. for the 2001 flocks was $10^{5.17}$ CFU/g. *Campylobacter* spp. prevalence levels in fecal samples ranged from 80 to 100%. No significant difference ($P > 0.05$) between the 1995 and the 2001 levels of *Campylobacter* spp. colonizing broiler feces was observed.

Table 2 also contains data for prechill carcasses representing the flocks assayed during 2001. Of the 450 carcass rinses collected, 441 (98.0%) tested positive for *Campylobacter* spp. The highest level of *Campylobacter* spp. was $10^{6.50}$ CFU per prechill carcass rinse (for individual 17 in flock 9). *Campylobacter* concentrations for all tested carcasses in flock 9 exceeded $10^{4.69}$ CFU per rinse, with concentrations for 3 of the 50 individual prechill carcasses exceeding $10^{6.0}$ CFU per rinse. *Campylobacter* prevalence levels in flocks ranged from 92 to 100% of the individual prechill carcasses tested.

Table 2 also contains data for the fully processed carcasses from the flocks assayed in 2001. Of the 450 carcass rinses collected, 381 (84.7%) tested positive for *Campylobacter* spp. The highest level of *Campylobacter* spp. was $10^{6.23}$ CFU per carcass rinse (for individual 1 in flock 9). *Campylobacter* concentrations for all tested carcasses in flock 9 exceeded $10^{3.74}$ CFU per rinse. *Campylobacter* prevalence levels for fully processed carcasses ranged from 66 to 100% across the flocks tested in 2001. Generally, when the frequency of positive carcasses within a flock was reduced, there was also a reduced level of *Campylobacter* spp.

Table 1 contains data on the mean levels of *Campylobacter* spp. in fecal droppings, prechill broiler carcasses, and postchill (fully processed) broiler carcasses for the nine flocks sampled in 2001. No significant correlation between *Campylobacter* spp. levels recorded for the fecal samples and those recorded for the prechill carcasses was observed. A regression analysis demonstrated that this relationship was not significant ($P > 0.05$). A coefficient of determination of 63% between levels of *Campylobacter* spp. for prechill carcasses and those for fully processed carcasses was statistically significant ($P < 0.05$). This relationship between prechill and postchill carcasses is expressed as a linear function in Figure 1 and corresponds to a correlation coefficient (Pearson's r) of 0.79. No correlation ($P > 0.05$) between levels of *Campylobacter* spp. in feces and those on fully processed carcasses was observed.

Figure 2 depicts the frequency of selected ranges of *Campylobacter* contamination for fully processed carcasses tested in 1995 and 2001. In 1995, the most frequently observed range of contamination was $10^{4.1}$ to $10^{5.0}$ CFU per carcass (52%). In 2001, the most frequent ranges were $10^{2.1}$ to $10^{3.0}$ CFU per carcass and $10^{3.1}$ to $10^{4.0}$ CFU per carcass (22 and 44%, respectively). The average (mean) level of contamination detected for fully processed carcasses in 2001 ($10^{3.05}$ CFU per carcass) was significantly reduced ($P < 0.001$) compared with the mean level detected in 1995 ($10^{4.11}$ CFU per carcass).

DISCUSSION

The intestinal tract of a chicken may harbor $>10^7$ CFU of *Campylobacter* spp. per g of intestinal contents without

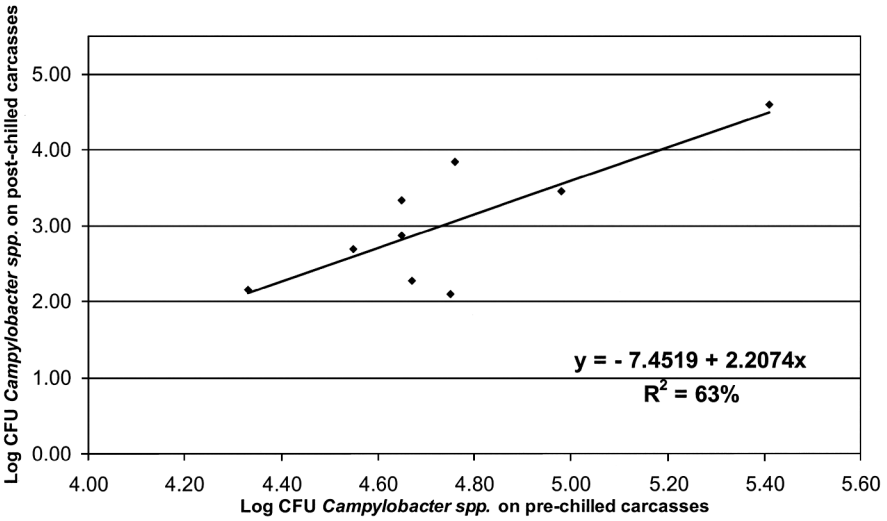

FIGURE 1. *Coefficient of determination for levels of* Campylobacter *spp. on pre-chill and postchill carcasses in northeast Georgia in 2001. A value of 0.01 log_{10} CFU per carcass was assigned to samples with undetectable levels of* Campylobacter *spp.*

any apparent pathological consequences for the avian host *(18).* During poultry processing, spillage or cross-contamination by the intestinal contents may contaminate poultry carcasses *(12).* Fecal droppings provide nondestructive samples for use in determining the presence and levels of *Campylobacter* spp. in broiler flocks *(24).* The levels and frequency of the isolation of *Campylobacter* spp. from fecal samples reported in this study correspond well to those in previously published literature. Pokamunski et al. *(15)* reported that 80% of flocks sampled were colonized and that 85% of the broilers within those flocks were colonized. Neill et al. *(13)* found 11 of 12 flocks to be colonized by *Campylobacter.* Grant et al. *(8)* found 83% of broiler fecal samples to test positive for *Campylobacter,* with an average level of 6.6 log CFU of *Campylobacter* per g.

As illustrated in Table 2, the level assigned to samples with undetectable levels of *Campylobacter* spp. influences the corresponding statistical values. If a value of 0.01 log_{10} CFU/g (essentially, no *Campylobacter* spp. present) is assigned to samples with undetectable levels, an average of $10^{4.93}$ CFU/g is calculated for the fecal samples collected in 1995 and an average of $10^{5.16}$ CFU/g is calculated for samples collected in 2001. This 2001 value may be compared with an average of $10^{5.25}$ CFU/g if 1.60 log_{10} CFU/g (the level just below the detection limit) is assigned to samples with undetectable levels. The corresponding median of the median value was $10^{5.50}$ CFU/g. For fully processed carcasses, if a value of 0.01 log_{10} CFU per carcass was assigned to the 1995 samples with undetectable levels, the mean calculated for these samples was $10^{4.11}$ CFU per carcass, corresponding to a similarly obtained mean of $10^{3.03}$ CFU per carcass in 2001. A value of $10^{2.70}$ CFU per carcass corresponds to 1 colony per duplicate plate, with each plate containing 0.1 ml of the total 100-ml rinse volume. When a value of 2.69 log_{10} CFU per carcass was assigned to the 2001 samples with undetectable levels of *Campylobacter* spp., the mean was calculated as $10^{3.45}$ CFU per carcass. The use of the median as a statistical measure of contamination levels requires no estimation for the value assigned to samples with undetectable levels of

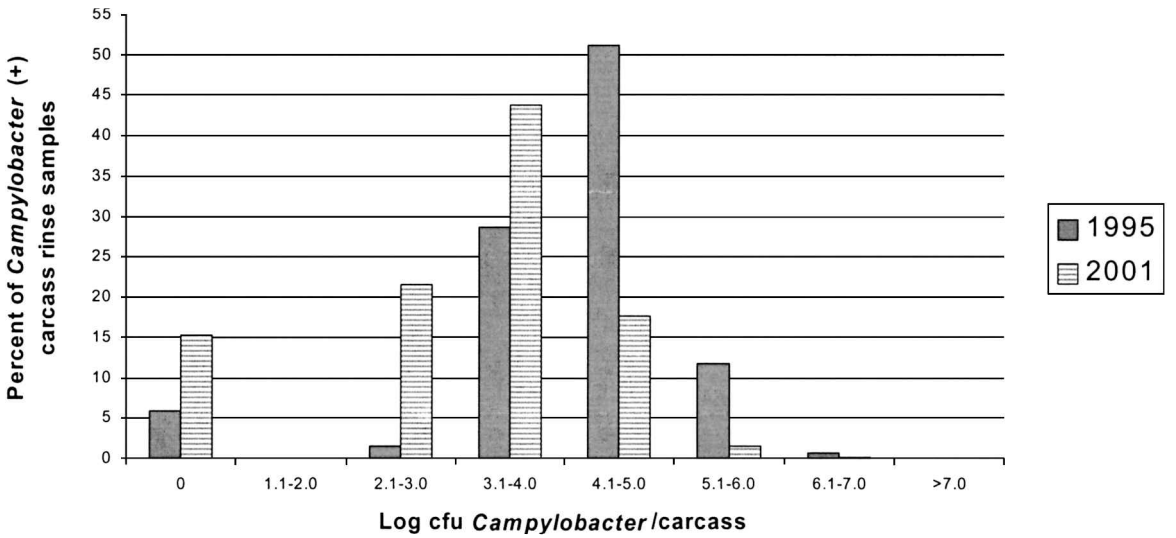

FIGURE 2. *Frequency of ranges of* Campylobacter *spp. levels on fully processed broiler carcasses. Data are represented in ranges of log_{10} values for the 1995 and 2001 samples. A value of 0.01 log_{10} CFU per carcass was assigned to samples with undetectable levels of* Campylobacter *spp.*

Campylobacter spp. The average median value for 2001 was found to be $10^{3.31}$ CFU of *Campylobacter* spp. per carcass. When the same measure was used for the 1995 rinses, the average median value was found to be $10^{4.30}$ CFU of *Campylobacter* spp. per carcass. When either mean or median statistical measures were used, the levels of *Campylobacter* spp. per carcass were reduced 10-fold. Consistent with the above trends, we observed an increase in the frequency of carcass rinse samples with undetectable levels of levels of *Campylobacter* spp. for the 2001 samples compared with the 1995 samples.

As the data presented in Table 1 indicate, a wide variation in levels of *Campylobacter* spp. within and among the flocks tested was seen. Often, differences of several orders of magnitude within a flock were observed, and we suggest that this variation may be related to the time following the introduction of *Campylobacter* spp. into the flock. If the organism had been introduced early in flock production, all of the broilers would likely have become exposed during the 8 weeks of production, and ample time would allow the development of large numbers of *Campylobacter* spp. in the intestinal tract. In a previous study, within 7 days of exposure to a single infected broiler, nearly 100% of experimental birds, ranging from 1 to 6 weeks of age, became colonized by *Campylobacter* spp. at levels of $10^{7.4}$ to $10^{8.2}$ CFU/g of cecal contents *(20).* In that study, the 70 naive broilers encountered homogeneous exposure in the enclosed environment (ca. 6 m^2). The experimental model used approximated commercial densities and assured a high level of infection. Conversely, if a single point source infects a commercial flock late in production, homogeneous exposure and colonization of individuals may not occur. In the present study, levels of *Campylobacter* spp. for individual droppings within a flock ranged from undetectable to $>10^6$ CFU/g of feces, which suggests that uniform exposure of a subset of the birds did not occur, while other birds were substantially colonized by the organism. For flocks 7 and 17, high levels of colonization were uniform. This finding might suggest that colonization occurred comparatively early in flock production and that homogeneous exposure and colonization of all housemates ensued.

Since the carcasses analyzed were the first to be processed on the day of sampling, contamination from another flock was unlikely. Transport crates are sometimes contaminated with *Campylobacter* and could potentially infect birds loaded into them *(21).* Individual birds within each of the flocks involved in the current study were 70 to 100% colonized prior to loading and transport. *Campylobacter* populations can increase 100-fold on carcasses during the transport of broilers from the farm to the processing plant *(19).*

Results obtained by Hood et al. *(10)* indicated that *Campylobacter* levels of $>10^6$ CFU per carcass may be encountered on market poultry. We suggest that *Campylobacter* levels found on the carcass may represent an important source of consumer exposure and a potential risk for infection. One of the aims of our study was to determine the distribution of contamination levels and prevalences of *Campylobacter* in flocks and carcasses. With this information, we hoped to determine whether variation in *Campylobacter* levels on the processed carcasses was related to the levels found on the broiler farm. Researchers have previously reported *Campylobacter* prevalence levels of 48, 94, and 98% for broiler carcasses *(10, 16, 22).* Smeltzer *(16)* also found carcasses to be contaminated with up to 5 log CFU of *Campylobacter* per carcass.

Table 1 presents the levels of *Campylobacter* spp. contamination for nearly 950 fully processed carcasses in 1995. The overall mean level reported for these samples was $10^{4.11}$ CFU per carcass. We suggest that the production and processing of broilers throughout the United States may be relatively uniform and that similar frequencies and levels of contamination might occur throughout the industry. Our data were gathered during the period when the CDC reported a human campylobacteriosis incidence of 23.5 cases per 100,000 individuals in the United States.

Tables 1 and 2 allow comparisons of the 1995 and 2001 levels of *Campylobacter* spp. in the fecal droppings of ~56-day-old broiler chickens. No significant differences ($P < 0.05$) between levels of *Campylobacter* spp. in feces collected in 1995 and levels in feces collected in 2001 were observed. Both the sources of broiler contamination and the frequency of broiler exposure appear to have remained constant. The sources of *Campylobacter* spp. appear to be diverse, and discussion regarding the optimum approach for the control of the organism during poultry production remains lively *(21).* Adequate risk assessment models are needed to determine the most appropriate and effective intervention strategies for use in the creation of on-farm, best-production strategies. The present study contributes to the datum-gathering process needed to generate such a risk assessment model.

Table 2 presents additional data required to describe and understand the relationship of on-farm levels of *Campylobacter* spp. to levels observed in the processing plant before carcasses were immersed in chiller tanks containing 40 to 50 ppm of chlorine. The frequency of prechill carcass rinses testing positive for *Campylobacter* spp. (98%) was higher than the frequency of fecal samples testing positive (94%) for the same flocks. This finding suggests that a homogenization in the distribution of *Campylobacter* spp. occurs during the catching, transport, and processing of poultry.

Fecal soiling and consequent increases in levels of *Campylobacter* spp. occur during the transport of broilers from production farms to the processing plant *(21).* We observed that the average level of *Campylobacter* spp. per carcass was lower than the mean levels of the organism per gram of feces. For the 2001 data, the antilogs of the geometric average, $10^{5.16}$ CFU/g of feces and $10^{4.75}$ CFU per prechill carcass, are calculated as 145,000 and 56,000 CFU, respectively, suggesting that a relatively small amount of fecal material contaminates the broiler carcass before the final rinse. The processing of poultry substantially and efficiently removes and limits fecal contamination of the carcasses. Certain flocks had the highest average fecal levels

of *Campylobacter* spp. and the highest levels of the organism for the prechill carcasses.

The observed correlation between levels of *Campylobacter* spp. for prechill carcasses and those for postchill (fully processed) carcasses was statistically significant (Fig. 1). The large number of samples collected in this study enabled this intuitive observation to be statistically validated. It should be recognized that the presence of *Campylobacter* spp. on the farm serves as the original and main source of carcass contamination, although the presence of the organism on the farm is not statistically correlated with carcass contamination. Various additional factors, such as weather or length of time taken for the transport of broilers to the processing plant, appear to confound any direct statistical relationship of production to processing.

The substantial number of samples gathered for the fully processed carcasses, which were evaluated for levels of *Campylobacter* spp. in both 1995 and 2001, also enable observations regarding the significant reduction in public exposure to the organism through poultry products (Fig. 2). The data obtained in the present study, combined with CDC data, suggest that one consequence of the observed logarithmic reduction in public exposure to *Campylobacter* spp. through poultry is the reduced frequency of human campylobacteriosis *(4).* The mere presence or absence of *Campylobacter* spp. on broiler carcasses is an inadequate measure by which to account for the reduction in human disease. Rather, the logarithmic reduction in exposure to the organism through poultry may be instructional for an understanding of causality. High levels of *Campylobacter* spp. may contribute to disease to a significantly greater extent than low levels do. Were an appropriate quantitative risk assessment developed, together with applicable intervention strategies to be used during production, appropriate expectations could be reasonably posited. Although the industry needs to dramatically reduce public exposure to *Campylobacter* spp., there is still an inconsistency in what can be achieved with poultry processing (Table 2, postchill carcasses, flock 9). Additional on-farm control measures that will result in consistent and acceptably low levels of *Campylobacter* spp. in processed broiler carcasses need to be developed and applied during broiler production. Rates of campylobacteriosis have dropped substantially in part because the industry has significantly reduced human exposure to *Campylobacter* spp., but the incidence of the disease in humans remains high. It remains possible that other important sources of the organism for the U.S. population exist.

The industry, consumer advocates, and the FSIS have assisted in significantly reducing the levels of *Campylobacter* spp. on processed carcasses. The impetus for this reduction was consumer demands for the enaction of federal HACCP regulations during the period of this study. The resulting regulations now require a frequency of *Salmonella*-positive carcasses within process lots produced in the United States of no more than 20% *(26).* Reduced levels of *Salmonella* prevalence may reflect changes arising from HACCP implementation *(27).* These changes also appear to have led to a reduction in *Campylobacter* spp. on processed poultry products in northeast Georgia.

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